CORRELATIONS OF THE WESTERN AUSTRALIAN PERMIAN AND PERMIAN OCEAN CIRCULATION PATTERNS

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Marine Permian sequences of the onshore Perth, Carnarvon, Canning and Bonaparte Basins have traditionally been correlated with Uralian, Tethyan and other sequences by means of invertebrate faunas. Marine benthonic invertebrate assemblages are ideal for using as precise zone indicators. Brachiopods in particular evolved rapidly, were characterised by short-lived species and yet were abundant in the Western Australian marine Permian. An integrated sequence of the eighteen brachiopod zones ranging in age from the Early Permian (Asselian) to high in the late Permian (Djhulfian) occurs in Western Australia. The most complete sequence of zones, in superpositional relationships, is to be found in the Carnarvon Basin against which the recognised zones for the Perth, Canning and Bonaparte Basins can be matched. The zones in the Perth and Carnarvon Basins have been integrated with palynological data and hence provide a valuable combined technique for intrabasinal and global correlations. Such combined techniques for correlation are all the more important for the Permian Period given the pronounced provincialism of most faunas and floras. The new brachiopod zone, the *Mingenewia anomala* Zone, characterised by the assemblage of the Mingenew Formation, Perth Basin, is proposed herein. The zone adds to the understanding of the faunal sequence of the Permian of the Perth Basin.

Improved time control results in refined models for interpreting patterns of Permian oceanic surface currents and their relationships to the faunas of the Permian basins of Western Australia. Surface current patterns appear unlikely to be able to explain the migration patterns of cooler water faunas across the equatorial regions of the Permian globe. However, deeper water currents (200–500 m) crossing the Equator, through the Tethyan seas, may have provided a mechanism for short-lived larval stages to have undertaken trans-equatorial migration and hence, in turn, explain the bipolarity of Permian invertebrate genera.

RECENTLY the Permian Subcommission of the International Commission on Stratigraphy (International Union of Geological Science) has approved names and boundary levels for series and stages of the Permian System based on marine successions (Jin et al. 1997). These successions are located respectively in the Urals (Lower Permian, Cisuralian Series, including the Asselian, Sakmarian, Artinskian and Kungurian Stages), southwest USA (Middle Permian, Guadalupian Series, including Roadian, Wordian and Capitanian Stages) and South China (Upper Permian, Lopingian Series, including the Wuchiapingian and Changhsingian Stages). It is of note that in this new scheme, the 'Middle' and 'Upper' Permian combined constitute a shorter period of absolute time than the Lower Permian which, in turn, tends to argue for a two-fold division of the Permian System (the classic view) rather than a three-fold division where the Middle Permian is merely the lower Upper in real terms (Archbold & Dickins 1997). The new proposals

of the Permian Subcommission, particularly the precise application of the Roadian to Capitanian time slice (lower Upper Permian as used herein) still present major problems for Gondwanan and Boreal correlations and considerable work is required to resolve these (see discussions by Archbold & Dickins 1997 and Waterhouse 1997). For the present review a scheme of subdivisions for the Permian utilising the classical Uralian stages, with supplementary Tethyan and south Chinese stages for the Late Permian is applied in the correlation tables.

The new Permian Subcommission standard global scheme does not make correlations easier for the vast bulk of Gondwana nor much of the Arctic Permian in Siberia and Canada (Waterhouse 1997). In the new scheme, primacy is given to marine groups such as fusulinid foraminiferids, conodonts and ammonoids. These groups are absent in most Gondwanan sequences. In terms of Gondwanan sequences only Western Australian
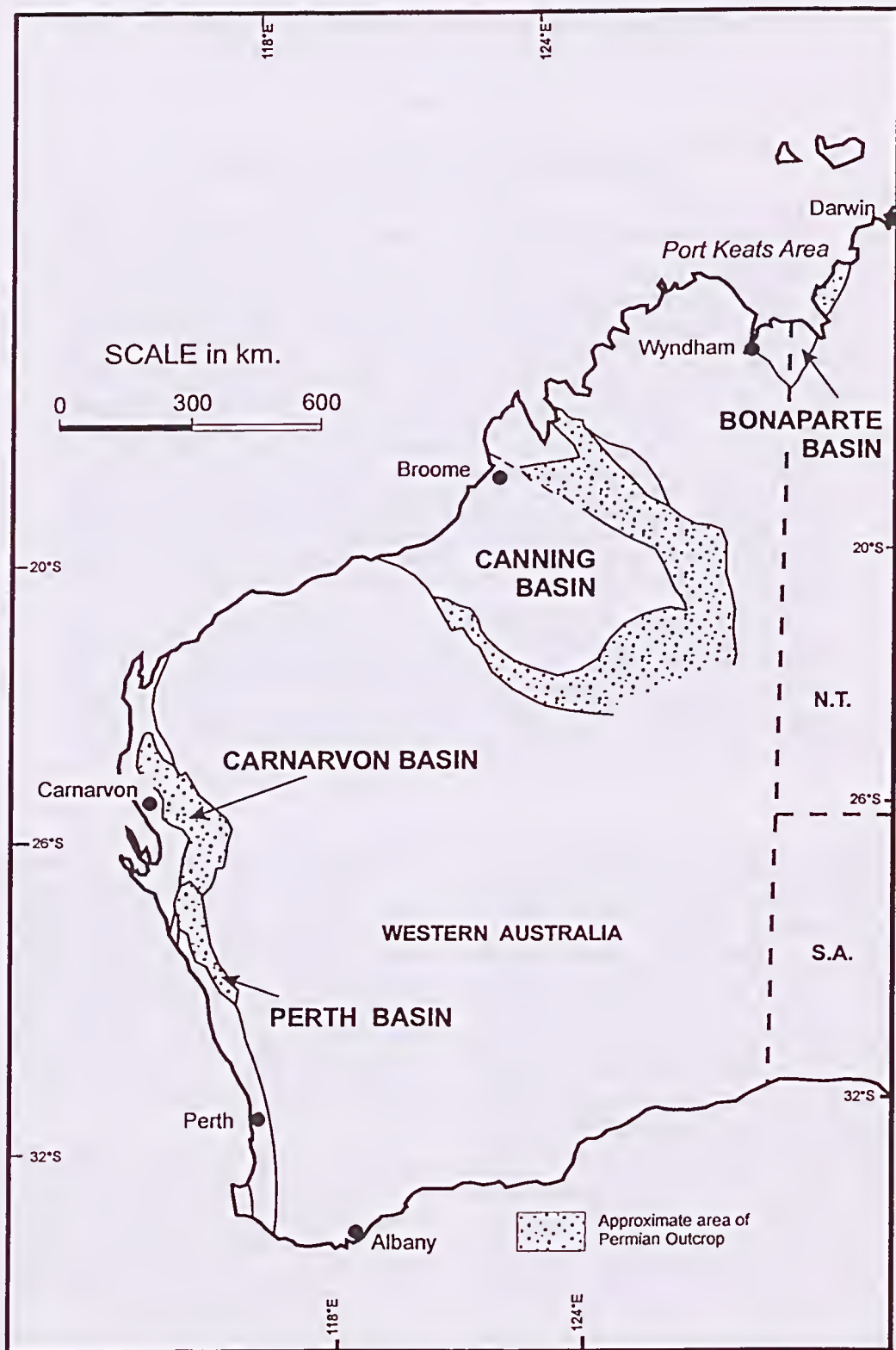
Permian sequences include a significant scattering of ammonoids (although usually only known from single point localities and often very few specimens) and a few, mostly endemic conodonts. These two groups provide point linkages to the international scheme adopted herein (as developed from such studies as Archbold & Dickins 1991, 1996; Archbold 1993a). However, they are inadequate for the purposes of detailed biostratigraphy, which requires a succession of changing benthonic zones, in sequence, with substantial assemblages of species for interbasinal correlations. It is of considerable interest that of all the 'selected fossil zones' for the integrated chronostratigraphic scheme for the Permian System regarded by Jin et al. (1997: 11) only one zone (the *Mesogondolella idahoensis* Zone) may be present in Western Australia (Nicoll & Metcalfe 1977), but even that zone has not been precisely matched against the Western Australian detailed, in sequence, zones based on brachiopod faunas (Archbold 1993a).

World Permian marine faunas demonstrate pronounced provincialism (e.g. see Archbold & Shi 1996). Within a province, precise interbasinal correlations are possible at the species and zonal level. Between provinces species may be distinct, as for brachiopods between the Westralian and Austrazean Permian Provinces of Australia (Archbold 1996a). Hence a number of marine groups of organisms may be required for precise interprovincial correlations. Some provinces by their nature may be transitional or intermediate in character and hence provide faunal assemblages that enable correlation between widely separated provinces. Such is the case of the Cimmerian (or peri-Gondwanan) provincial regions which permit correlation of the Westralian faunas with those of the Tethyan and Uralian Provinces. Tropical southwest USA Permian faunas, in the sense of provincialism, are analogous to the coldest water Permian faunas of Tasmania and hence represent an extreme variant of Permian faunas for correlation purposes (Archbold & Dickins 1997). As indicated by Ganelin et al. (1997: 33) these southwestern North American faunas are biogeographically isolated and still require further characterisation. The likelihood of precise matching of such zoned tropical faunas and their boundaries with those of Gondwanan faunas appears remote and hence severely limits the global value of this portion of the proposed 'global' scale.

THE MARINE PERMIAN OF WESTERN AUSTRALIA

Introduction

Since the initial proposal of the Permian System by Roderick Impey Murchison (1841a, 1841b, 1841c) and the full documentation of the system by Murchison and his colleagues (1845), the scope and subdivision of the Permian Period has changed dramatically. The Permian System, as originally envisaged, included the Kungurian, Ufimian, Kazanian and Tatarian stages as now used in modern Russian terminology (see Chuvashov 1993; Anfimov et al. 1993 for recent accounts in English). The Permian was extended downwards by such authors as Karpinsky (1874), Fredericks (1918) and Ruzhentsev (1954) to include the divisions defined as the Artinskian, Sakmarian and Asselian. The marine Permian sequences of the onshore Western Australian, Perth, Carnarvon, Canning and Bonaparte Basins (Figs 1, 2) and the basins of eastern Australia have traditionally been correlated with these Uralian stages and, more recently, with Tethyan stages for the Late Permian, by means of marine macro-invertebrate faunas.

Western Australian marine Permian faunas

Permian marine faunas of Western Australia are well summarised and illustrated in the edited volume by Skwarko (1993) which also provides extensive bibliographies on the earlier work on the marine faunas, palynofloras and stratigraphy of the Western Australian Basins. Ongoing work has continued on foraminiferids (Palmieri 1994), bivalve and gastropod molluscs (Archbold et al. 1996), brachiopods (Archbold 1993a, 1993b, 1995a, 1995b, 1996a, 1996b, 1998; Archbold & Shi 1993; Archbold & Thomas 1993), echinoderms (Webster 1990; Webster & Jell 1992), conodonts (Nicoll & Metcalfe 1997) and palynofloras (Backhouse 1991, 1993; Mory & Backhouse 1997). The first detailed attempt at a biostratigraphical zonation of the Western Australian Permian was that by Dickins (1963) who recognised six faunal stages (informally named Oppel-zones) based primarily on the stratigraphical distribution of bivalve and gastropod taxa in the Perth, Carnarvon and Canning Basins.

Fig. 1. Onshore Permian marine basins of Western Australia.

Subsequently, Arehbold (1988a, 1993a, 1993b, 1995a, 1998) has developed a seheme of eighteen braehiopod Oppel or Assemblage zones, eaeh named on the basis of a partieularly charaeteristic species, for the Western Australian marine Permian (Fig. 3). This series of zones is best developed in
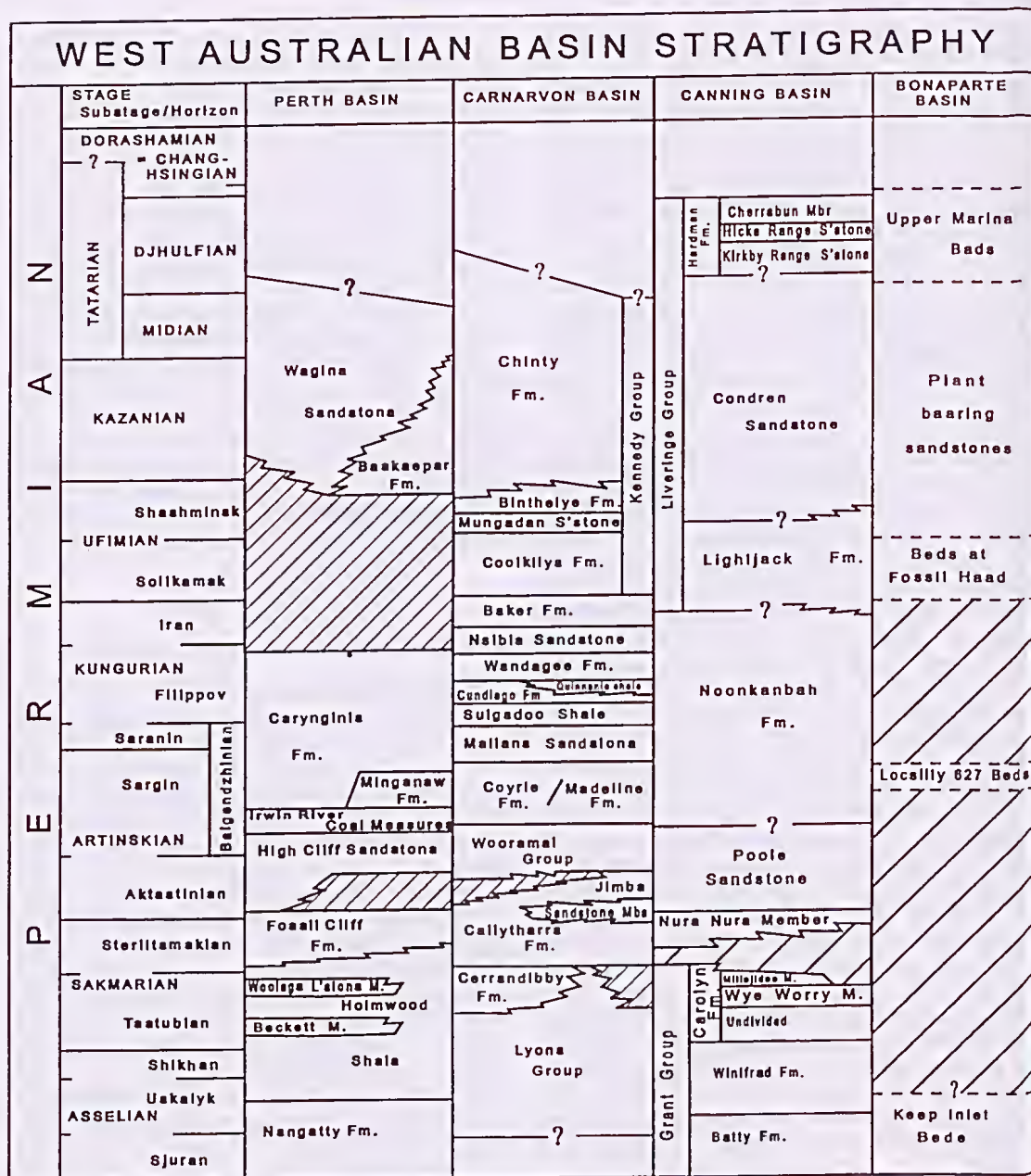

WEST AUSTRALIAN BASIN STRATIGRAPHY

STAGE Subatage/Horizon		PERTH BASIN	CARNARVON BASIN	CANNING BASIN		BONAPARTE BASIN
DORASHAMIAN — ? — = CHANG-HSINGIAN	TATARIAN			Hardman F.E. Cherrabun Mbr / Hicks Range S'stone / Kirkby Range S'atone — ? —	Kennedy Group / Liveringa Group	Upper Marina Bads
DJHULFIAN		Wagina Sandatona	Chinty Fm.	Condren Sandatone		Plant baaring sandstones
MIDIAN						
KAZANIAN		Baakaepar Fm.	Binthelye Fm. / Mungadan S'stone			
Shashminak	UFIMIAN		Coolkilya Fm.	Lighljack Fm.		Beds at Fossil Haad
Sollkamak			Baker Fm.	— ? —		
Iran			Nalbla Sandatone			
KUNGURIAN Fillppov		Carynginla Fm.	Wandagee Fm. / Cundlego Fm Quinnnrio shale / Sulgadoo Shale / Mallana Sandalona	Noonkanbah Fm.		
Saranin	Balgendzhinian		Coyrie / Madeline Fm. / Fm.			Locallly 627 Bads
Sargin		Minganaw Fm. / Irwin River Coal Measures				
ARTINSKIAN		High Cliff Sandatona	Wooramal Group	Poole Sandstone		
Aktastinian			Jimba Sandatona Mba	Nura Nura Member		
Sterlitamakian		Fossil Cliff Fm.	Callytharra Fm.			
SAKMARIAN		Woolaga L'alona M. / Holmwood / Beckett M.	Cerrandibby Fm.	Millajldee M. / Wye Worry M. / Undivided	Carolyn F. / Grant Group	
Taatublan		Shala	Lyona Group	Winlfrad Fm.		
Shikhan						
Uakalyk ASSELIAN		Nangatty Fm.	— ? —	Batty Fm.		Keep Inlot Bede
Sjuran						

Fig. 2. Summary stratigraphy of the onshore Permian marine basins and the proposed international correlations.

Fig. 3. Summary marine correlation scheme showing brachiopod zones, faunal stages (from Dickins 1963) and international correlations.

SUMMARY SCHEME

STAGE Substage/Horizon	INTEGRATED W.A. BRACHIOPOD ZONES	FAUNAL STAGES	GLOBAL STAGES
DORASHAMIAN —?— = CHANG- HSINGIAN (TATARIAN)	/////		CHANGHSINGIAN
DJHULFIAN (TATARIAN)	*Waaganoconcha (Wlmanoconcha) imperfecta* ///// *Livaringia magnifica*	F2 / F / F1	WUCHIAPINGIAN —?—
MIDIAN (TATARIAN)	/////	—?—	CAPITANIAN —?—
—?— KAZANIAN	/////	E	WORDIAN —?—
	Sulciplica occidentalis		
Sheshminsk —UFIMIAN—	/// ? // *Fusispirifer coolkilyaensis*		ROADIAN
Solikamsk	*Neochonetes (Sommerialia) afanasyevaa*	D2	—?—
Iren	*Svalbardia thomasi*		
KUNGURIAN Filippov	*Neochonetes (S.) nalbiaensis* *Fusispirifer wandagaensis* *Fusispirifer cundlagoensis* *Tornquistia magna*		KUNGURIAN
Saranin (Baigendzhinian)	*Fusispirifer byroensis*	D1	
Sargin (Baigendzhinian)	*Wyndhamia colemani*		ARTINSKIAN
ARTINSKIAN (Baigendzhinian)	*Echinalosia pridari* ? ///		
Aktastinian	*Neochonetes (S.) magnus* *Strophalosia jimbaensis*	C	
Sterlitamakian SAKMARIAN	*Strophalosia irwinensis*	B	SAKMARIAN
Tastublan	*Trigonotrata occidentalis* ?	A	
Shikhan Uskalyk ASSELIAN	*Lyonia lyoni* - - ? - -		ASSELIAN
Sjuren	/////		

the sequences of the Carnarvon Basin although important additional zones are present in the Perth and Canning Basin sequences. Brachiopods are highly useful as zonal indicators; they evolved rapidly, species were invariably short-lived and they were abundant, usually dominating benthonic assemblages. Species often occur in several of the Western Australian basins and hence are valuable for interbasinal correlations. Onshore or offshore drill core can also yield abundant specimens which in turn can be valuable for age control (Archbold 1988b, 1995a, 1995b). Molluscan data, consisting of ammonoid, gastropod and bivalve species, provides significant support for the brachiopod scheme. The Western Australian marine zonation scheme is comparable to that developed for the Russian Kolyma–Omolon biogeographical Province of the Boreal Realm (Kashik et al. 1990) in terms of the use of ammonoids, bivalves and gastropods.

At least two other palaeontological approaches are also highly significant for interbasinal correlations. Palynological zonation schemes have long held primacy in their application to subsurface correlations in Western Australia (see Mory & Backhouse 1997 for a brief review of the development of the palynological zonation schemes). However, international palynological correlations are not widely established for the bulk of the Permian of Australia, although considerable potential exists for latest Permian correlations (Foster & Jones 1994). Ages assigned largely rely on marine macrofossil data.

Detailed foraminiferal zonation schemes also offer considerable potential for correlation purposes and recent work has indicated not only their value for zonation purposes (Palmieri 1990, 1994; Draper et al. 1990) but also their potential for international correlation (Palmieri et al. 1994). Nevertheless, despite records of key species from Western Australian lithostratigraphic units (Palmieri 1994; Palmieri et al. 1994) such records must, in turn, be related to the palynological data and marine macrofossil data (as in Palmieri et al. 1994 for the Bowen Basin, Queensland). However the data provided by Palmieri at al. (1994) proposing a Kazanian age for part of the subsurface Lightjack Formation (Canning Basin) are less well supported because outcrop Lightjack Formation has yielded the diagnostic ammonoid *Daubichites* (see Glenister et al. 1993) and brachiopods that indicate a significant turnover of species and even genera and hence maybe taken to indicate an Ufimian age.

Each onshore west Australian basin with marine Permian sequences is reviewed below in terms of the brachiopod zonation scheme and key species of other marine groups for international correlations. The sequence of brachiopod zones is provided in Fig. 3 and the lithostratigraphical units in which the zones are to be found are indicated below.

PERTH BASIN

The Perth Basin Permian outcrops of the Irwin River area have yielded important data for the Early Permian (Sakmarian–Artinskian) zonation scheme and correlations. Key ammonoid species indicate that a Sakmarian sequence is well represented in the Holmwood Shale and the Fossil Cliff Formation (Leonova 1997). Brachiopod data indicate a Late Sakmarian (Sterlitamakian) age for the *Strophalosia irwinensis* Zone, the oldest brachiopod zone yet recognised in the Perth Basin sequences. Correlation of this zone with the Carnarvon Basin (lower Callytharra formation *sensu* Mory & Backhouse 1997) and the Canning Basin (Cuncudgerie Sandstone, southern Canning Basin and the Nura Nura Member of the Poole Sandstone, Fitzroy Trough) is firmly indicated by shared brachiopod species. Both of these basins have yielded Sterlitamakian ammonoids.

From the *Strophalosia irwinensis* Zone of the Fossil Cliff Formation (at times considered to be the uppermost member of the Holmwood Shale) the following brachiopods have been described: *Strophalosia irwinensis* Coleman, *Neochonetes (Sommeriella) prattii* (Davidson), *Etherilosia etheridgei* (Prendergast), *Aulosteges baracoodensis* Etheridge, *Aulosteges spinosus* Hosking, *Taeniothaerus irwinensis* Coleman, *Callytharrella callytharrensis* (Prendergast), *Costatumulus irwinensis* (Archbold), *Stenoscisma* sp., *Globiella foordi* (Etheridge). *Neospirifer hardmani* (Foord), *Trigonotreta neoaustralis* Archbold & Thomas, *Elivina hoskingae* Archbold & Thomas, ?*Cyrtella* sp., *Spirelytha fredericksi* Archbold & Thomas, *Phricodothyris occidentalis* Archbold & Thomas, *Tomiopsis woodwardi* Archbold & Thomas, *Cleiothyridina baracoodensis* Etheridge and *Fletcherithyris* sp. cf. *F. hardmani* Campbell.

The *Neochonetes (Sommeriella) magnus* Zone from the basal High Cliff Sandstone of Woolaga Creek, although clearly younger than the Fossil Cliff Formation on the basis of superpositional relationships, is less well constrained for the purposes of international correlation purpose. Data has been presented elsewhere (Archbold 1998) indicating that on evolutionary grounds, the fauna is younger than that of the Jimba Jimba Calcarenite (Carnarvon Basin, upper Callytharra

Formation *sensu* Mory & Backhouse 1997) but older than the fauna of the Coyrie–Madeline Formations of the basal Byro Group of the Carnarvon Basin. Brachiopods from the *N. (S.) magnus* Zone that have been described include: *Streptorhynchus* sp., *Neochonetes (Sommeriella) magnus* Archbold, *Chonetinella* sp., strophalosiid sp., *Aulosteges ingens* Hosking, *Taeniothaerus quadratiformis* Archbold, *Costatumulus occidentalis* Archbold, *Neospirifer (Quadrospira) woolagensis* Archbold, *Occidalia shahi* Archbold, *Woolagia playfordi* Archbold, ?*Cyrtella* sp., *Tomiopsis rarus* Archbold & Thomas, *Cleiothyridina perthensis* Archbold, *Composita* sp., *Gilledia woolagensis* Campbell and *Hoskingia skwarkoi* Archbold.

Isolated by faulting, the brachiopod fauna of the Mingenew Formation is formally named herein the *Mingenewia anomala* Zone. Approximately correlatable with the Coyrie–Madeline Formations (Carnarvon Basin), as proposed by Dickins (1965), it is not clear precisely which zone of the lower Byro Group of the Carnarvon Basin offers the best correlation (Archbold 1996b). It is possible that more than one zone may be present but endemicity of species hampers a precise correlation. In view of the presence of the strophalosiid genus *Echinalosia* in the Mingenew assemblage, it is assumed that the *Mingenewia anomala* Zone probably correlates with the *Echinalosia prideri* Zone of the Carnarvon Basin as shown in Fig. 3. Brachiopod species described from the Mingenew Formation include: *Streptorhynchus* sp., *Tornquistia* cf. *magna* Archbold, *Neochonetes (Sommeriella) robustus* Archbold, *Strophalosia enantiensis* Archbold, *Echinalosia simpsoni* Archbold, *Mingenewia anomala* Archbold, *Taeniothaerus roberti* Archbold, *Coolkilella maitlandi* Archbold, *Cundaria aquilaformis* Archbold, *Syrella occidenta* Archbold, *Fusispirifer byroensis* Glauert, *Fusispirifer* sp., *Neospirifer* sp., *Occidalia mingenewensis* (Archbold), *Cleiothyridina* sp., *Hoskingia nobilis* (Etheridge) and *Gilledia* cf. *woolagensis* Campbell.

A brachiopod fauna discovered west of the Irwin Sub-Basin was assigned to the *Sulciplica occidentalis* Zone. It was retrieved from cores from Beharra Springs 2 and is also present in Woodada 3 and Beekeeper 1 (Archbold 1995a). Assigned a general Ufimian age in 1995, the present author now assigns the zone to the Latest Ufimian (and extending into the Early Kazanian) on the basis of superpositional palynological data (Mory & Backhouse 1997) and the assignment of older faunas and palynological floras from the Coolkilya Sandstone (Carnarvon Basin) to the Ufimian on the basis of ammonoid data. The fauna described from the Beekeeper Member of

the Wagina Formation includes: *Etherilosia* sp., *Spiriferella* sp., *Neospirifer* spp., *Fusispirifer* cf. *avicula* (Morris), *Sulciplica occidentalis* Archbold, *Cleiothyridina* sp. and *Spirigerella* sp.

CARNARVON BASIN

The onshore marine Permian succession of the Carnarvon Basin contains the most detailed representation of brachiopod zones, numerous key international correlation points based on ammonoids, a few new discoveries of conodonts (Nicoll & Metcalfe 1997) and a well controlled sequence of palynological zones (Mory & Backhouse 1997). In terms of available biostratigraphical data, the Carnarvon Basin possesses the most detailed biostratigraphical sequence for the Early and early Late Permian of Western Australia.

The development of the biostratigraphy of the onshore Carnarvon Basin has been summarised in recent studies (Archbold 1993a; Mory & Backhouse 1997). A few pertinent comments are offered here. The ages of the two oldest brachiopod zones (the *Lyonia lyoni* and *Trigonotreta occidentalis* Zones) are constrained by superpositional positions below Sterlitamakian ammonoid occurrences from the Callytharra Formation (Archbold 1995b). Lower horizons of the Lyons Group yield the characteristic species of the *Lyonia lyoni* Zone: *Lyonia lyoni* (Prendergast), *Rhynchopora australasica* Archbold, *Kiangsiella* sp., *Grumantia* cf. *costellata* Clarke, *Cyrtella australis* Thomas, *Tomiopsis notoplicatus* Archbold & Thomas and *Trigonotreta lyonsensis* Archbold & Thomas. Key species of the *Trigonotreta occidentalis* Zone have been described from upper horizons of the Lyons Group as follows: *Trigonotreta occidentalis* Thomas, *Grumantia* cf. *costellata* Clarke, *Lyonia lyoni* (Prendergast), *Cyrtella australis* Thomas, *Permorthotetes crespinae* Thomas, *Linoproductus* sp., *Taeniothaerus* sp., ?*Callytharrella* sp., *Spiriferella* sp. and *Tomiopsis notoplicatus* Archbold & Thomas. This zone is also known from the Carrandibby Formation with the key species *Neochonetes (Sommeriella) obrieni* Archbold and *Tomiopsis notoplicatus* Archbold & Thomas.

The *Strophalosia jimbaensis* Zone from the Jimba Jimba Calcarenite (now considered to be the upper part of a redefined Callytharra Formation; see Mory & Backhouse 1997) shares a new species of the conodont *Vjalovognathus* with the Sterlitamakian *Strophalosia irwinensis* Zone below and many (but not all) of the brachiopod species are shared. The two zones are considered to be close in age but,

on the basis of stratigraphical superposition the *S. jimbaensis* Zone is considered to be Early Artinskian in age.

Brachiopods from *S. irwinensis* Zone of the lower part of the Callytharra Formation (as defined by Mory & Backhouse 1997) include those for the Perth Basin Fossil Cliff Formation (excluding *Taeniothaerus irwinensis* Coleman) and *Permorthotetes callytharrensis* Thomas, *Permorthotetes camerata* Thomas, *Arctitreta plicatilis* (Hosking), *Tornquistia occidentalis* Archbold, *Stictozoster senticosa* (Hosking), *Comuquia australis* Archbold, *Lethamia obscurus* Archbold, *Dyschrestia micracantha* (Hosking), *Camerisma callytharrensis* (Hosking), *Myodelthyrium dickinsi* (Thomas), *Latispirifer callytharrensis* Archbold & Thomas, *Neospirifer foordi* Archbold & Thomas, *Neospirifer* sp., *Imperiospira dickinsi* Archbold & Thomas *Fusispirifer carnarvonensis* Archbold & Thomas, *Tomiopsis* sp., ?*Fredericksia* sp. nov., *Gjelispinifera decipiens* (Hosking), *Lamnaespina papilionata* (Hosking), *Callispirina* sp. nov. and *Hustedia* sp. nov.

The *Strophalosia jimbaensis* Zone includes the following species: *Streptorhynchus* sp., *Permorthotetes* cf. *lindneri* Thomas, *Neochonetes (Sommeriella) cockbaini* Archbold, *Neochonetes (Sommeriella) hockingi* Archbold, *Strophalosia jimbaensis* Archbold, ?*Reedoconcha* sp., *Aulosteges* sp., *Callytharrella callytharrensis* (Prendergast), *Costatumulus* cf. *irwinensis* (Archbold), *Globiella flexuosa* (Waterhouse), ?*Cyrtella* sp., *Neospirifer hardmani* (Foord), *Neospirifer* cf. *foordi* Archbold & Thomas, *Fusispirifer* sp., *Crassispirifer condoni* Archbold & Shi, *Trigonotreta neoaustralis* Archbold & Thomas, *Tomiopsis* cf. *rarus* Archbold & Thomas, *Spirelytha* sp., *Cleiothyridina ovalis* Shi, *Cleiothyridina* cf. *baracoodensis* (Etheridge) and *Hoskingia* sp.

The *Neochonetes (Sommeriella) magnus* Zone of the Perth Basin is apparently absent in the Carnarvon Basin but is considered to be correlatable with, at least, the upper part of the Wooramel Group. Fossiliferous localities attributed to the Wooramel Group (some of which may be upper Callytharra Formation *sensu* Mory & Backhouse 1997) all appear to belong to the *Strophalosia jimbaensis* Zone (see Archbold 1991).

The Byro Group includes some eight brachiopod zones indicating rapid evolution of the phylum. The lowest zones (the *Echinalosia prideri*, *Wyndhamia colemani* and *Fusispirifer byroensis* Zones) are considered here to be late Artinskian in age. This equates with part of the older usage of Baigendzhinian. The Permian Subcommission proposals (Jin et al. 1997) now place the Artinskian–Kungurian boundary at the base of the Saraninsk Horizon in the Urals sequences which reduces the scope of the classic Artinskian. This is in order to accommodate the conodont *Neostreptognathodus pnevi* into the Kungurian below the Filippovian Horizon, the base of which was the more traditional Artinskian–Kungurian boundary. Hence several of the western Australian brachiopod zones (the *Tornquistia magna* Zone up to the *Fusispirifer wandagensis* Zone), previously indicated to be of Late Artinskian age, are now placed in the Kungurian (cf. Archbold & Dickins 1996; Fig. 3). The discovery of the conodont *Vjalovognathus shindyensis* Kozur in the Coyrie Formation has been interpreted by Nicoll & Metcalfe (1997) to indicate a Kungurian age for the base of the Byro Group. However the range of this conodont species is poorly known in Western Australia and Timor and it appears that other endemic species of *Vjalovognathus* in the Carnarvon Basin succession range through two or up to four brachiopod zones based on the stratigraphical ranges provided by Nicoll & Metcalfe (1997). As a result, the present author considers that the occurrence of *V. shindyensis* may also indicate a broader time range of a Late Artinskian and early Kungurian age.

In ascending order the brachiopod zones of the Byro Group include the species listed below for the respective lithostratigraphical units.

The *Echinalosia prideri* Zone from the lower part of the Madeline Formation includes: *Permorthotetes* sp., *Streptorhynchus* sp., *Kiangsiella condoni* Thomas, *Gatia superba* Archbold, *Neochonetes (Sommeriella) robustus* Archbold, *Echinalosia prideri* (Coleman), *Aulosteges lyndonensis* Coleman, *Costatumulus* sp., *Pseudosyrinx*? *sinuosa* Thomas and *Neospirifer (Quadrospira) plicatus* Archbold & Thomas.

The *Wyndhamia colemani* Zone from the upper part of the Madeline Formation includes: *Streptorhynchus* sp., *Wyndhamia colemani* Archbold, *Etherilosia* sp., *Aulosteges ingens* Hosking, *Costatumulus* sp., *Crassispirifer rostalinus* (Hosking), *Fusispirifer byroensis* (Glauert), *Tomiopsis pauciplicatus* Archbold & Thomas, *Spiriferella* sp., *Spirelytha* sp., *Cleiothyridina* sp. and *Hoskingia trigonopsis* (Hosking).

The *Fusispirifer byroensis* Zone overlaps with the *Wyndhamia colemani* Zone of the upper Madeline Formation and extends into younger strata (Mallens and Bogadi Sandstones). The fauna is restricted and includes *Aulosteges ingens* (Hosking), *Fusispirifer byroensis* (Glauert), *Crassispirifer rostalinus* (Hosking), *Imperiospira* sp. and *Hoskingia trigonopsis* (Hosking).

The restricted fauna of the *Tornquistia magna* Zone from the Bulgadoo Shale appears to represent a fauna adapted to an anoxic muddy sea-floor and includes the limited assemblage of *Tornquistia magna* Archbold, *Neochonetes (Sommeriella)* sp., *Fredericksia?* sp. nov. and *Hoskingia kennediensis* Campbell.

The moderately diverse *Fusispirifer cundlegoensis* Zone is well represented in the Cundlego Formation and includes: *Permorthotetes* sp., *Streptorhynchus hoskingae* Thomas, *Tornquista* cf. *tropicalis* Grant, *Demonedys granti* Archbold, *Neochonetes (Sommeriella) tenuicapillatus* Archbold, *Quinquenella australis* Archbold, *Etherilosia prendergastae* (Coleman), *Wyndhamia multispinifera* (Prendergast), *Retimarginifera perforata* Waterhouse, *Spiriferella cundlegoensis* Archbold & Thomas, *Imperiospira* sp., *Fusispirifer cundlegoensis* Archbold & Thomas, *Hoskingia kennediensis* Campbell and *Gilledia* cf. *homevalensis* Campbell. It is also represented by the somewhat restricted fauna of the Quinnanic Shale which has yielded *Semilingula occidentaustralis* (Archbold), *Streptorhynchus hoskingae* Thomas, *Neochonetes (Sommeriella) tenuicapillatus* Archbold, *Fusispirifer quinnaniensis* Archbold & Thomas, *Spiriferella cundlegoensis* Archbold & Thomas and *Spirelytha kashirtsevi* Archbold.

The diverse *Fusispirifer wandageensis* Zone, known from the Wandagee Formation, includes the following species: *Streptorhynchus hoskingae* Thomas, *Tornquistia gregoryi* Archbold, *Neochonetes (Sommeriella) tenuicapillatus* Archbold, *Etherilosia complectens* (Etheridge), *Wyndhamia* sp., *Lialosia kimberleyensis* (Prendergast), *Taeniothaerus coolkiliensis* Coleman, *Taeniothaerus miniliensis* Coleman, *Taeniothaerus teicherti* Coleman, *Dyschrestia colemani* Archbold, *Retimarginifera perforata* Waterhouse, *Coolkilella bella* (Etheridge), *Neospirifer amplus* Archbold & Thomas, *Imperiospira franzjosefi* Archbold & Thomas, *Fusispirifer wandageensis* Archbold & Thomas, *Cartorhium imperfectum* Archbold, *Crassispirifer pinguis* Archbold & Thomas, *Trigonotreta dickinsi* Archbold & Thomas, *Spiriferella australasica* (Etheridge), *Spirelytha miloradovichi* Archbold & Thomas, *Tomiopsis teicherti* Archbold & Thomas, *Hustedia basedowi* (Etheridge), *Cleiothyridina macleayana* (Etheridge), *Yochelsonia thomasi* Stehli, *Hoskingia wandageensis* Campbell and *Gilledia* cf. *homevalensis* Campbell.

The *Neochonetes (Sommeriella) nalbiaensis* Zone, documented from the Nalbia Sandstone has yielded the more limited assemblage of *Neochonetes (Sommeriella) nalbiaensis* Archbold, *Svalbardia narelliensis* Archbold, *Wyndhamia* sp.,

Lialosia kimberleyensis (Prendergast), *Magniplicatina* sp. nov., *Imperiospira* sp., *Spirelytha miloradovichi* Archbold & Thomas, *Fusispirifer* sp. and *Hoskingia* cf. *wandageensis* Campbell.

Dickins (1963) and Dickins et al. (1989) argued that the single specimen of the ammonoid *Paragastrioceras wandageense* Teichert (1942) came from the Baker Formation (the lowest part of the Coolkilya Formation as interpreted by Teichert 1952) rather than from the Nalbia Sandstone as proposed by other authors. The preservation of the specimen, as a black ferruginous internal mould, is typical of the style of preservation of brachiopods from the Baker Formation. *P. wandageense* is a significant species because of its close similarity to *P. kungurense* Mirskaya (1948), also discussed by Bogoslovskaya (1976), from the Late Kungurian Iren Horizon of Cisuralia. *P. wandageense* appears to therefore indicate a firm correlation for the Baker Formation with Irenian Substage of the Kungurian. The history and development of the type Kungurian sequences has been reviewed by Chuvashov (1997) who has emphasised the difficulty of recognising the stage outside the Cisuralian region. He also viewed the data indicating that the lower part of the Ufimian type sections (i.e. the Solikamsk Horizon) should be included within the Kungurian. Kungurian ammonoids can be recognised from the Pechora Basin (Chuvashov 1997) and Pai-Khoy and Vaigach Islands (Bogoslovskaya 1997).

The *Svalbardia thomasi* Zone characterises the fauna of Baker Formation which includes the brachiopods *Permorthotetes teicherti* Thomas, *Svalbardia thomasi* Archbold, *Lialosia kimberleyensis* (Prendergast), *Aulosteges* sp., *Imperiospira campbelli* Archbold & Thomas, *Fusispirifer* sp. and *Cleiothyridina* cf. *macleayana* (Etheridge).

Russian authors (e.g. Popov 1963; Andrianov 1968, 1985; Bogoslovskaya 1976, 1988) have long insisted that the ammonoid *Daubichites* (which is known from two horizons in the Coolkilya Sandstone) is of Ufimian age. Recent work indicates that the Boreal *Daubichites* assemblage is of late Ufimian age (i.e. equivalent to the Sheshma Horizon of the Ufimian, which is equivalent to the Roadian stage of North America) as discussed by Kotlyar (1997). The occurrence of a specimen of *Daubichites* from an horizon usually assumed to be the same as that of *P. wandageense* (i.e. in the Baker Formation), as indicated by Teichert (1942), was in fact discovered some 1.3 km from the specimen of *P. wandageense* on the opposite flank of a synclinal structure. Precise bed by bed relationships are not known for the two localities and hence it is possible that the

Daubichites specimen eame from a slightly higher horizon than the *Paragastrioceras* speeimen which, in turn, may indicate that the Kungurian–Ufimian boundary may be within the Baker Formation. It is difficult to eonclude other than that the age of this stratigraphieally lowest specimen ean be anything other than early Ufimian (or latest Kungurian) in age. This, in turn, indieates that the ammonoid *Daubichites* may have appeared earlier in Western Australia than in the Boreal Realm, a feature also known for other bipolar faunal elements. Marine faunas of the type lower Ufimian (Solikamsk Horizon) are of Early Permian aspect as are those of the Baker Formation and Coolkilya Sandstone (Diekins et al. 1989). Nevertheless, the brachiopod faunas of the Coolkilya Sandstone demonstrate the appearance of many new speeies distinetive from those of the underlying stratigraphieal units. The oecurrence of *Spiriferella etheridgei* Arehbold & Thomas in the Coolkilya Sandstone is of signifieanee beeause it is a large species with a sharp dorsal fastigium, a feature eharaeteristic of several late Permian Arctic speeies. Notwithstanding the diseussions in Dickins et al. (1989) or as shown in Arehbold & Dickins (1996) the faunas of the Coolkilya Sandstone are now interpreted by me as being Ufimian in age (Arehbold 1993a; Mory & Baekhouse 1997). At present, no evidence is available to indicate that any Permian fauna occurs in outerop in the Carnarvon Basin that is younger than Ufimian in age.

The *Neochonetes (Sommeriella) afanasyevae* Zone whieh is found in throughout the Coolkilya Sandstone (excluding the topmost beds), ineludes the species *Permorthotetes teicherti* Thomas, *Streptorhynchus johnstonei* Thomas, *Derbyia* sp., *Neochonetes (Sommeriella) afanasyevae* Archbold, *Chonetinella* sp., *Aulosteges* sp., *Dyschrestia* sp., *Retimarginifera waterhousei* Arehbold, *Coolkilella coolkilyaensis* (Archbold), *Imperiospira campbelli* Archbold & Thomas, *Fusispirifer kennediensis* Arehbold & Thomas, *Spiriferella etheridgei* Arehbold & Thomas, *Spirelytha stepanoviana* Arehbold & Thomas, *Cleiothyridina* sp. and *Yochelsonia thomasi* Stehli.

The topmost beds of the Coolkilya Sandstone have yielded a limited brachiopod fauna referred to the *Fusispirifer coolkilyaensis* Zone with the speeies *Taeniothaerus* sp. and *Fusispirifer coolkilyaensis* Arehbold.

CANNING BASIN

The onshore Canning Basin marine Permian is noteworthy for the oecurrence of Late Permian (Djhulfian) marine faunas and a rather ineomplete sueeession of Sakmarian to Ufimian brachiopod zones when compared with the sueeession of zones in the Carnarvon Basin. A few ammonoids confirm braehiopod correlations with the Carnarvon Basin sueeessions and aid as international referenee points. Sparse eonodont data is of eonsiderable interest but is not matehed against brachiopod zones and hence provides data points not related to existing brachiopod biostratigraphieal schemes. Rigorous matehing of marine faunas against palynologieal zonations are also laeking. Considerable work is required to produce an integrated biostratigraphy for the Canning Basin and to determine the nature and duration of breaks in the sedimentary sueeessions.

Sakmarian brachiopod faunas have been deseribed by Archbold (1990 1995a) and their ages summarised (Archbold 1993a). The Late Artinskian *Echinalosia prideri* Zone may be present in the Noonkanbah Formation (Arehbold 1993a) but it is by no means confirmed. The faunas of the Noonkanbah Formation are known from incomplete seetions and spot localities and, as a result, the nature of the Noonkanbah Formation in terms of the eompleteness of the sequenee is still in doubt. The reeord of *Mesogondolella idahoensis* (Youngquist, Hawley & Miller) from the Noonkanbah Formation is of eonsiderable interest (Nieoll & Metcalfe 1997). Although not matched with any brachiopod zone, no reeorded zone from the Noonkanbah Formation appears to be of latest Kungurian age as would normally be indieated by the species reeord (Jin et al. 1997) if taken out of eontext of the Western Australian sueeession. Faunas from the elassic Mount Marmion area are a firm mateh with those of the Wandagee Formation of the Carnarvon Basin. A number of loealities high in the Noonkanbah Formation with *Svalbardia narelliensis* indieate the presenee of the *Neochonetes (Sommeriella) nalbiaensis* Zone. The Lightjaek Formation is eharaeterised by the *Neochonetes (Sommeriella) afanasyevae* Zone and the ammonoid *Daubiehites* indicating, as interpreted herein, an Ufimian age.

The youngest marine Permian faunas of onshore Australia are known from the Hardman Formation and are of Djhulfian age. Two zones are known with many shared species (Arehbold 1988a) and equivalent marine faunas are known from the Bonaparte Basin.

In aseending order the following braehiopod zones are known from the onshore Canning Basin as documented by the deseribed braehiopod species listed below.

The Early Sakmarian (Tastubian) *Trigonotreta occidentalis* Zone is known from the Wye Worry Member, Carolyn Formation of the Grant Group (species present: *Neochonetes (Sommeriella) obrieni* Archbold, *Etherilosia carolynae* Archbold, *Costatumulus* sp. and *Trigonotreta* sp.) and the Calytrix Formation of the Grant Group (species present: ?*Streptorhynchus* spp., *Arctitreta* sp., *Neochonetes (Sommeriella) obrieni* Archbold, *Etherilosia calytrixi* Archbold, *Costatumulus capillatus* (Waterhouse), ?*Cyrtella* sp., *Trigonotreta* sp., ?*Martinia* sp. and *Spiriferellina* sp.).

The Late Sakmarian (Sterlitamakian) *Strophalosia irwinensis* Zone (with advanced *Metalegoceras* and *Propopanoceras* ammonoid species from the Nura Nura Member) is known from the Cuneudgerie Sandstone (species present: *Permorthotetes lindneri* Thomas, *Tornquistia subquadratus* Archbold, *Strophalosia irwinensis* Coleman, *Aulosteges* cf. *baracoodensis* Etheridge, *Taeniothaerus* cf. *irwinensis* Coleman, *Costatumulus irwinensis* (Archbold), *Cyrtella koopi* Archbold, *Myodelthyrium dickinsi* (Thomas), *Trigonotreta neoaustralis* Archbold & Thomas and *Spirelytha* cf. *fredericksi* Archbold & Thomas) and the Nura Nura Member of the Poole Sandstone (species present: *Streptorhynchus* sp., *Permorthotetes lindneri* Thomas, *Neochonetes (Sommeriella) prattii* (Davidson), *Neospirifer foordi* Archbold & Thomas, *Cratispirifer nuraensis* Archbold & Thomas, *Myodelthyrium dickinsi* (Thomas), *Tomiopsis woodwardi* Archbold & Thomas and *Fletcherithyris* cf. *hardmani* Campbell).

A few localities low in the Noonkanbah Formation may indicate the presence of the Artinskian *Echinalosia prideri* Zone represented by the species *Kiangsiella* cf. *condoni* Thomas and *Costiferina wadei* (Prendergast).

Localities high in the Noonkanbah Formation (e.g. Mount Marmion) have yielded many representatives of the *Fusispirifer wandageensis* Zone of presumed early Kungurian age (species present: *Neochonetes (Sommeriella) tenuicapillatus* Archbold, *Permorthotetes guppyi* Thomas, *Permorthotetes* cf. *camerata* Thomas, *Kiangsiella* sp., *Streptorhynchus costatus* Thomas, *Streptorhynchus variabilis* Thomas, *Arctitreta crassinurus* (Thomas), *Etherilosia complectens* (Etheridge), *Wyndhamia multispinifera* (Prendergast), *Lialosia kimberleyensis* (Prendergast), *Taeniothaerus miniliensis* Coleman, *Retimarginifera perforata* Waterhouse, *Coolkilella bella* (Etheridge), *Stenoscisma* sp., *Neospirifer amplus* Archbold & Thomas, *Neospirifer (Quadrospira) postplicatus* Archbold & Thomas, *Imperiospira franzjosefi* Archbold & Thomas, *Crassispirifer pinguis* Archbold & Thomas, *Trigonotreta dickinsi* Archbold & Thomas,

Fusispirifer wandageensis Archbold & Thomas, *Spiriferella australasica* (Etheridge), *Spirelytha miloradovichi* Archbold & Thomas, *Tomiopsis teicherti* Archbold & Thomas, *Hustedia basedowi* (Etheridge), *Cleiothyridina macleayana* (Etheridge), *Fletcherithyris* cf. *hardmani* Campbell, *Yochelsonia thomasi* Stehli, *Hoskingia* cf. *grandis* Campbell, *Hoskingia* cf. *wandageensis* Campbell, *Gilledia* cf. *homevalensis* Campbell and ?*Hemiptychina* sp.).

From top beds of the Noonkanbah Formation the species *Svalbardia narelliensis* Archbold has been described indicating the presence of the *Neochonetes (Sommeriella) nalbiaensis* Zone.

The Lightjack Formation, with the ammonoid *Daubichites*, includes the following representatives of the *Neochonetes (Sommeriella) afanasyevae* Zone: *Permorthotetes guppyi* Thomas, *Streptorhynchus perfidiabadensis* (Etheridge), *Neochonetes (Sommeriella) afanasyevae* Archbold, *Etherilosia* sp., *Costatumulus*? sp., *Costatispirifer gracilis* Archbold & Thomas, *Tomiopsis globosus* Archbold & Thomas, *Tomiopsis balgoensis* Archbold & Thomas and *Yochelsonia stehlii* Campbell.

The Kirkby Range Member of the Hardman Formation is characterised by the Midian–Djhulfian *Liveringia magnifica* Zone with: *Streptorhynchus luluigui* Hosking, *Waagenites stani* Archbold, *Notolosia millyiti* Archbold, *Liveringia magnifica* Archbold, *Neospirifer grandis* Archbold & Thomas, *Tomiopsis hardmani* Archbold & Thomas and *Cleiothyridina* sp.

The youngest zone in the Canning Basin from the Cherrabun Member of the Hardman Formation is the Djhulfian *Waagenoconcha (Wimanoconcha) imperfecta* Zone with the ammonoid *Cyclolobus*. Brachiopod species include: *Streptorhynchus* cf. *pelargonatus* (Schlotheim), *Derbyia hardmani* Thomas, *Neochonetes (Sommeriella) hardmani* Archbold, *Neochonetes (Sommeriella)* sp., *Notolosia dickinsi* Archbold, *Aulosteges reclinis* Coleman, *Taeniothaerus fletcheri* Coleman, *Megasteges fairbridgei* (Coleman), *Megasteges septentrionalis* (Etheridge), *Waagenoconcha (Wimanoconcha) imperfecta* Prendergast, *Latispirifer amplissimus* Archbold & Thomas, *Neospirifer grandis* Archbold & Thomas, *Tomiopsis hardmani* Archbold & Thomas, *Hustedia* sp., *Cleiothyridina penta* Prendergast, *Cleiothyridina* spp., *Fletcherithyris hardmani* Campbell and *Hoskingia grandis* Campbell.

BONAPARTE BASIN

Marine Permian faunas from the onshore Bonaparte Basin have been known for over 100 years and

have recently been reviewed by Archbold et al. (1996). Four brachiopod zones are recognised onshore and equivalent faunas of the youngest *Waagenoconcha (Wimanoconcha) imperfecta* Zone are recognised offshore from the Sahul Platform (Archbold 1988b).

The *Wyndhamia colemani* Zone, the oldest zone yet recognised onshore is known from one outcrop locality in the Port Keats District, of the Northern Territory. Species identified and described are *Neochonetes (Sommeriella) robustus* Archbold, *Wyndhamia* cf. *colemani* Archbold and *Neospirifer (Quadrospira)* cf. *plicatus* Archbold & Thomas, providing a firm correlation with the zone in the Carnarvon Basin.

The *Neochonetes (Sommeriella) afanasyevae* Zone is known from outcrops at Fossil Head, Port Keats District, where it is characterised by the species *Neochonetes (Sommeriella) afanasyevae* Archbold, *Streptorhynchus perfidiabadensis* (Etheridge) and *Imperiospira campbelli* Archbold & Thomas. Firm correlation with the Coolkilya Sandstone of the Carnarvon Basin is indicated.

Outcrops of beds in the Port Keats Area, originally described as the Upper Marine Beds of the Port Keats Group, have yielded representatives of the two youngest brachiopod zones of the Canning Basin. The *Liveringia magnifica* Zone is represented by *Streptorhynchus luluigui* (Hosking), *Aulosteges reclinis* Coleman, *Neospirifer grandis* Archbold & Thomas and *Tomiopsis hardmani* Archbold & Thomas.

The *Waagenoconcha (Wimanoconcha) imperfecta* Zone is represented by the species: *Derbyia hardmani* Thomas, *Waagenites* sp., *Aulosteges reclinis* Coleman, *Megasteges septentrionalis* (Etheridge), *Waagenoconcha (Wimanoconcha) imperfecta* Prendergast, *Costiferina thomasi* Archbold, *Leptodus nobilis* Waagen, *Neospirifer grandis* Archbold & Thomas, *Latispirifer amplissimus* Archbold & Thomas, *Tomiopsis hardmani* Archbold & Thomas, *Cleiothyridina* sp., *Hustedia* sp. and *Stenoscisma* sp.

WESTERN AUSTRALIA AND PANGAEA

Many elements of the Western Australian marine brachiopod faunas are closely related to those of the peri-Gondwanan or Cimmerian regions that now make up much of the Asian region. Links between the Western Australian faunas and these regions serve to supplement and test the models for the breakup of Gondwana during the Permian and later times. Metcalfe (1996) has provided a comprehensive account of the breakup of the Tethyan–Gondwanan margin and Archbold & Shi (1996) have provided a summary of the regional provincialism shown by Tethyan–Gondwanan margin faunas and those of Western Australia. It is not proposed to review here the extensive literature on the breakup models and faunal provincialism (the above two references provide large reference lists on the subjects). Recent reviews of global Permian biogeography include those of Jin & Shang (1997) and Grunt & Shi (1997) and these place the Western Australian and southeast Asian faunas in a global setting. Once marine faunas are biostratigraphically well known, as is now the case for Western Australian faunas, migration patterns in and out of marine provinces such as the Westralian Province can be used to construct temperature curves and regional surface ocean circulation models (Archbold & Shi 1995, 1996). Previous workers who developed schematic maps showing surface ocean currents include Frakes & Crowell (1971), Ziegler et al. (1981) and Ross & Ross (1985). Bardossy (1994) utilised the patterns of currents proposed by Ziegler et al. (1981). Kutzbach et al. (1990) modelled the ocean circulation pattern of an idealised Panthalassic Ocean with a simplified Tethyan Gape. Archbold & Shi (1996) provided sketch maps of finer time slices showing hypothetical surface currents associated with a Tethys embayment with scattered microcontinents. Surface currents were restricted to those defined as cold and warm whereas with improved knowledge of cold, temperate and tropical faunas it is now possible to suggests three temperature categories (cold, temperate and tropical) of surface currents and show how these have changed during the general global warming and with the northward movement of Pangea during the Permian. These new maps are provided in Figs 4–8. It should be noted that the presumed equatorial counter-current is not shown on the maps.

One of the most intriguing aspects of the biogeography of Permian marine faunas is the bipolarity of genera of different groups (e.g. small foraminiferans, Bryozoa, Ammonoidea, Bivalvia, etc.). This phenomenon is also well known for brachiopods since the work of Fredericks (1931). The present author has progressively documented over nearly 20 years that many Western Australian genera of brachiopods also occur in Boreal faunas. These include *Semilingula*, *Neochonetes (Sommeriella)*, *Svalbardia*, *Tornquistia*, *Demonedys*, *Quinquenella*, *Arctitreta*, *Streptorhynchus*, *Strophalosia*, *Wyndhamia*, *Echinalosia*, *Costatumulus*, *Waagenoconcha*, *Spirelytha*, *Tomiopsis*, *Neospirifer*, *Spiriferella*, *Crassispirifer*, *Fusispirifer*, *Rhynchopora* and others that require documentation. Often
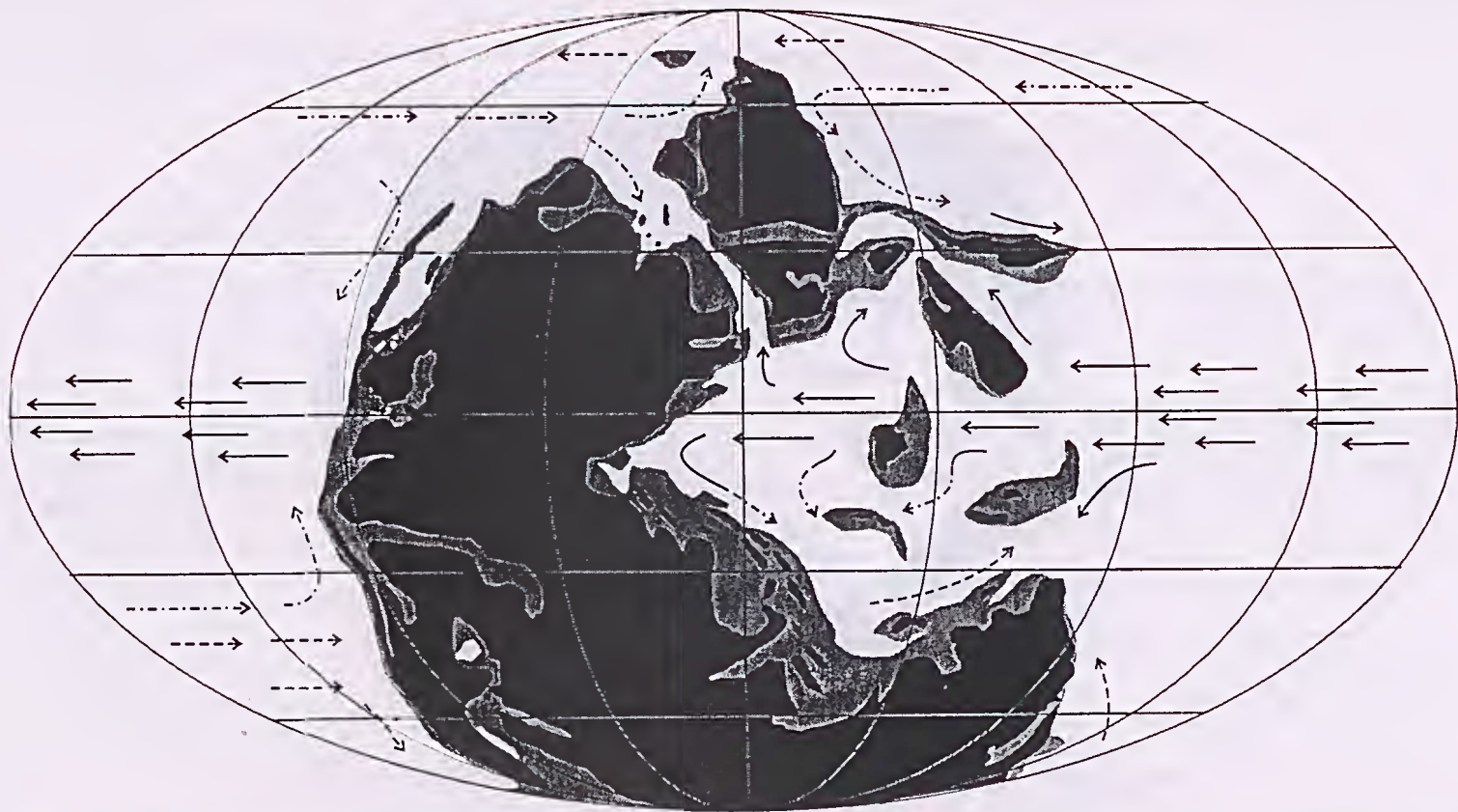
Fig. 4. Surface global ocean circulation pattern for the Asselian–Tastubian time slice (298–289 Ma). Solid line arrows, tropical water; dashed line arrows, cold water; dot-dash line arrows, temperate water. Global reconstructions for this figure and Figs 5–9 are based on those provided by Ziegler & Gibbs (1996).
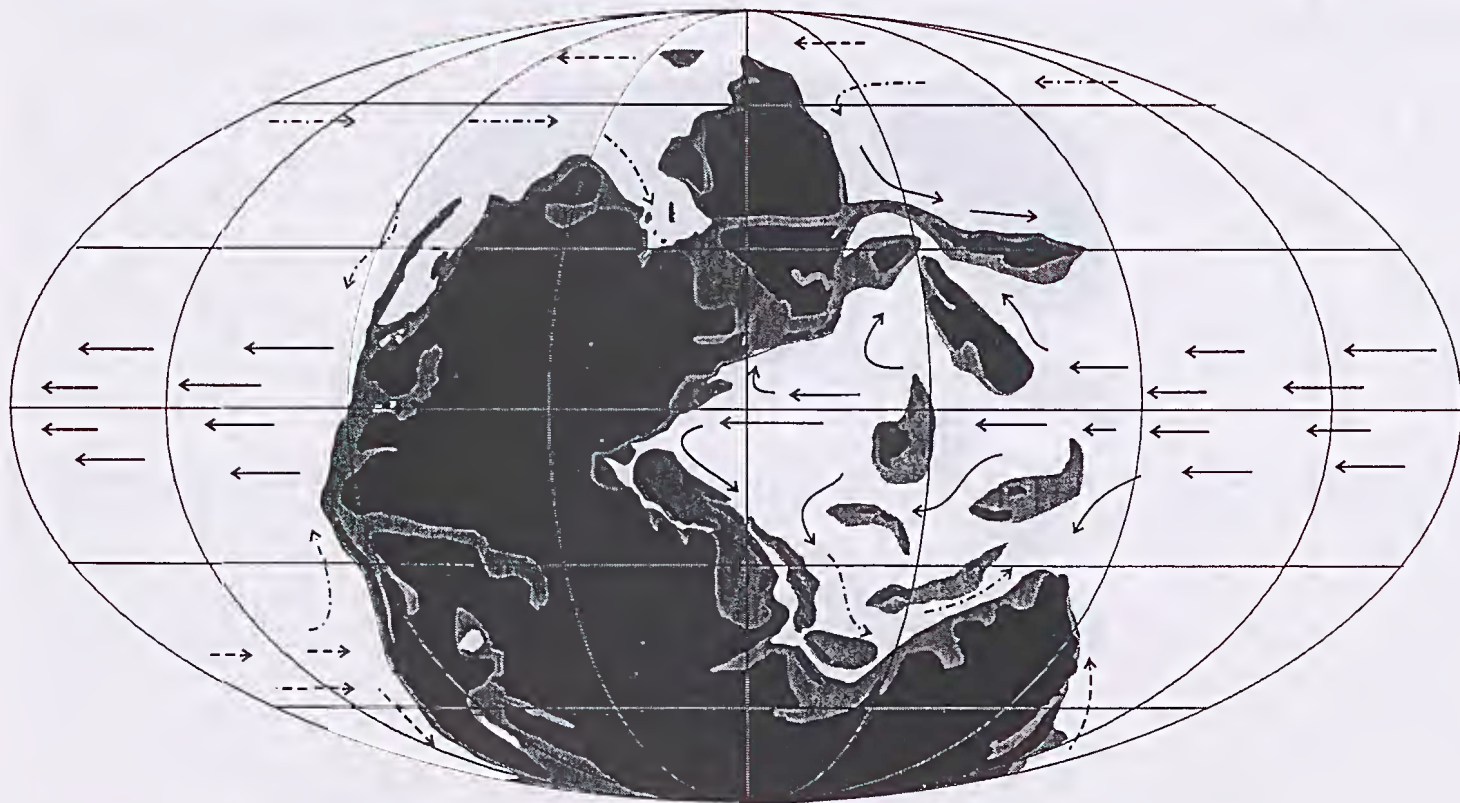
Fig. 5. Surface global ocean circulation pattern for the Sterlitamakian–Aktastinian time slice (289–279 Ma). Symbols as for Fig. 4.
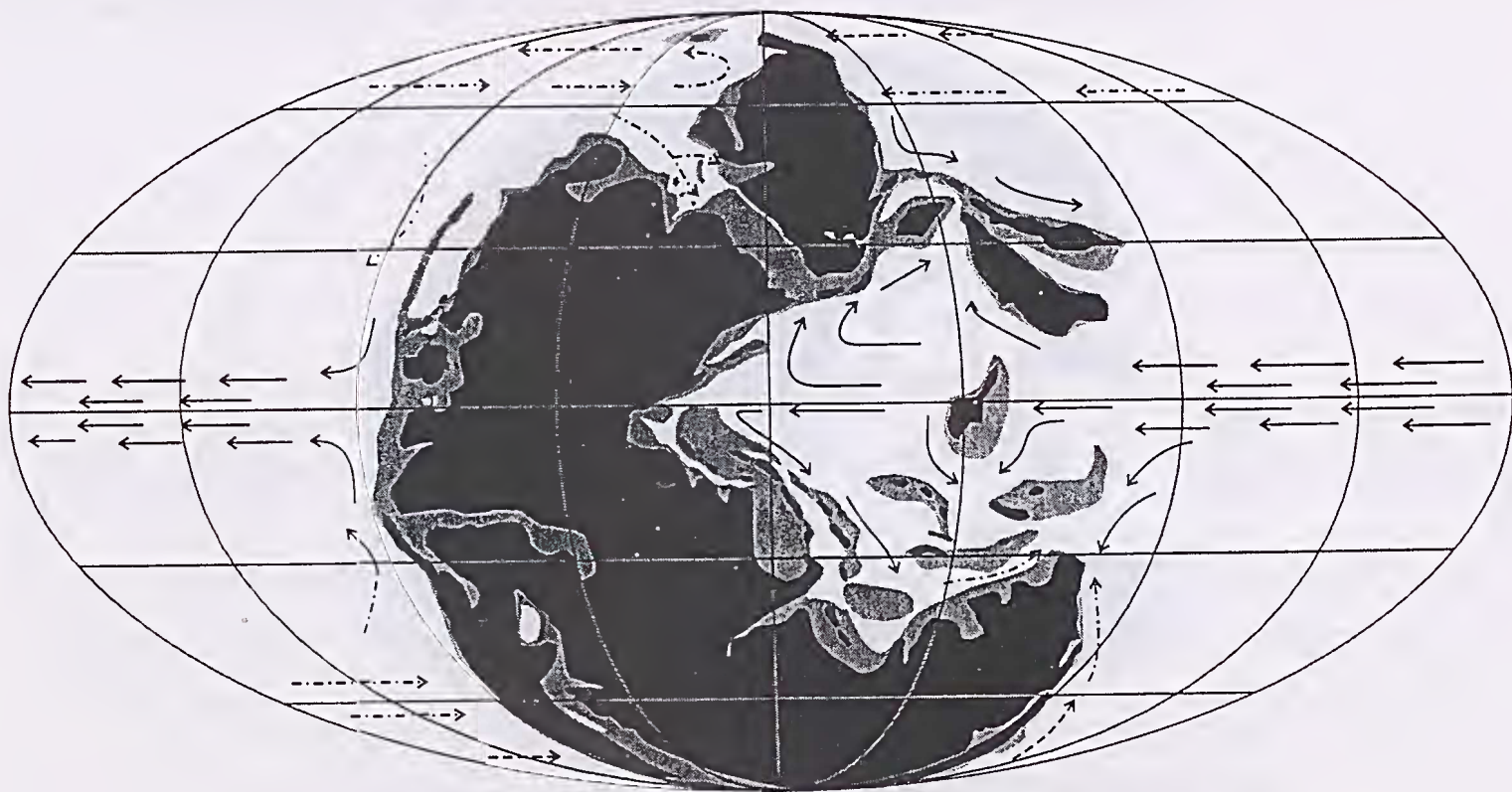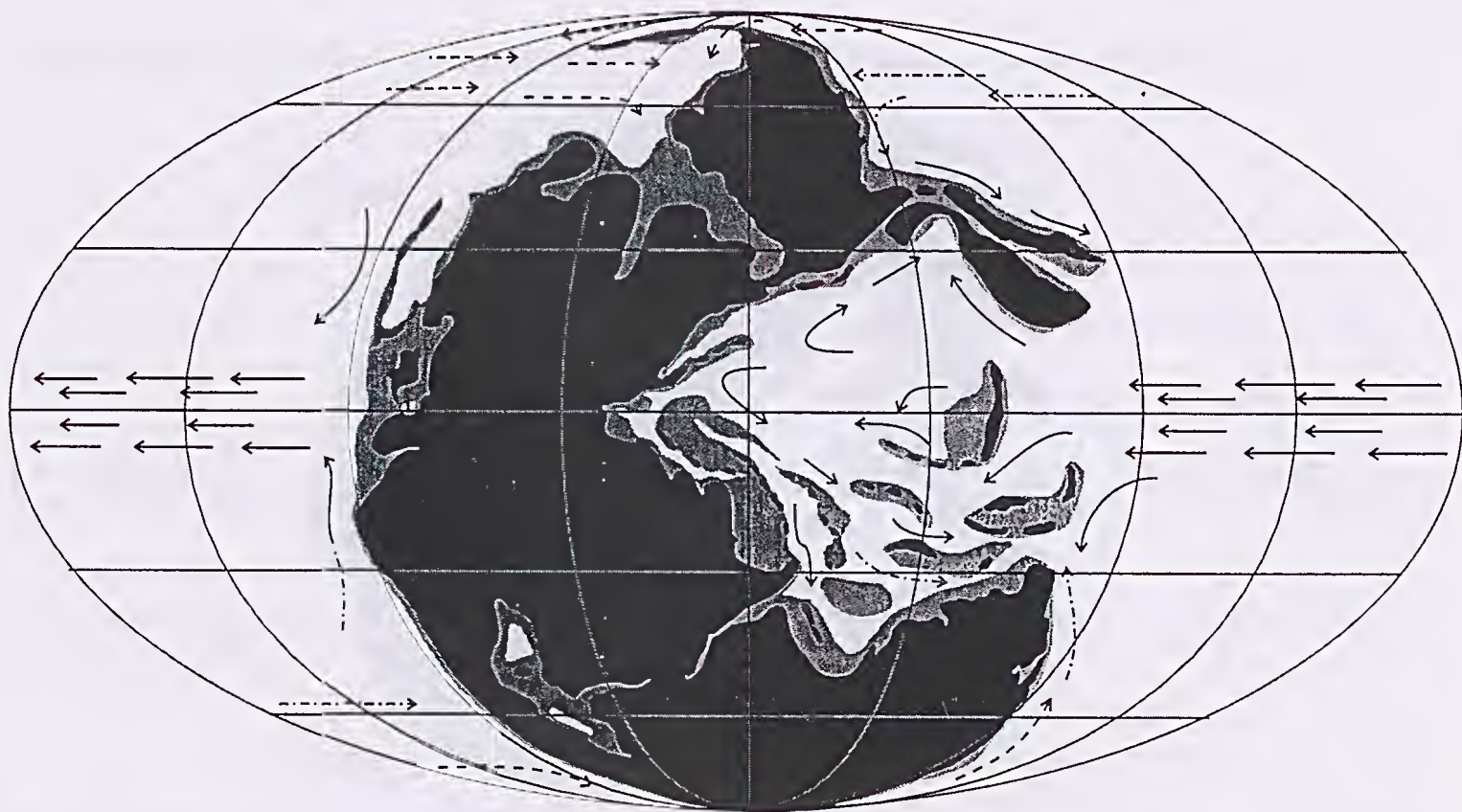
Fig. 6. Surface global ocean circulation pattern for the Baigendzhinian–Solikamsk time slice (279–268 Ma). Symbols as for Fig. 4.

Fig. 7. Surface global ocean circulation pattern for the Sheshminsk–Kazanian time slice (268–260 Ma). Symbols as for Fig. 4.
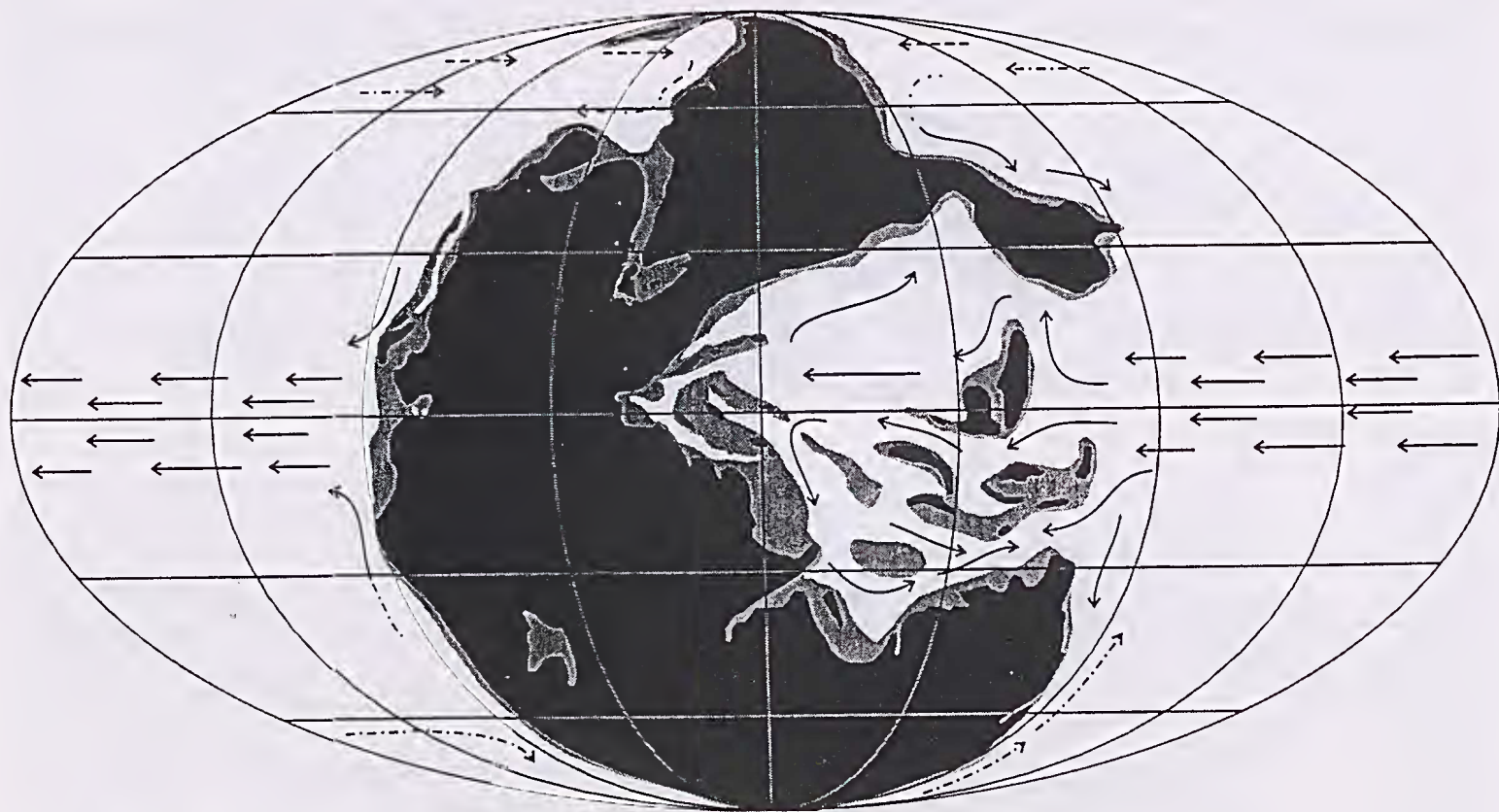
Fig. 8. Surface global ocean circulation pattern for the Tatarian time slice (260–251 Ma). Symbols as for Fig. 4.
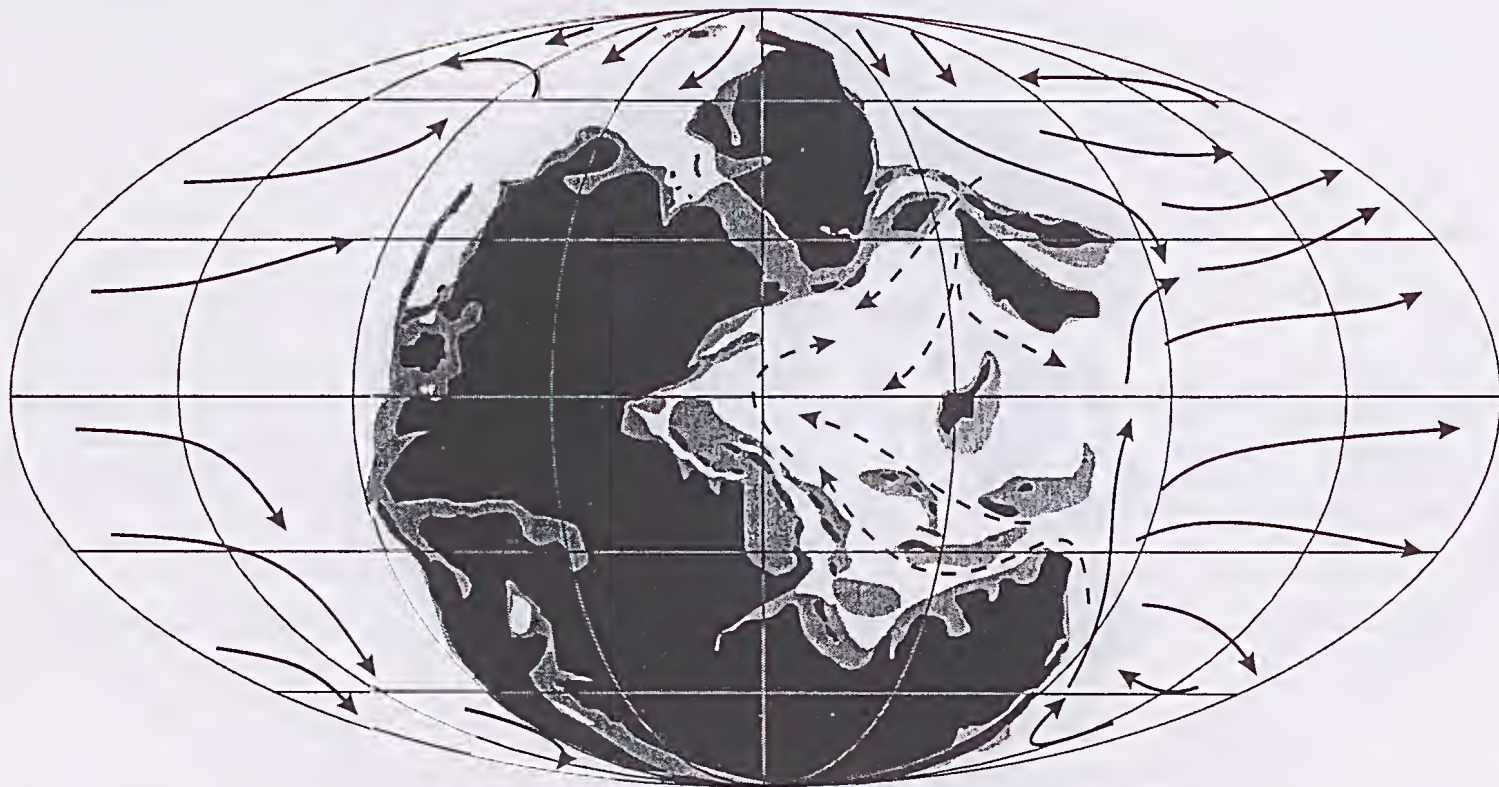
Fig. 9. Schematic deeper water global ocean circulation pattern for the Kungurian–Ufimian time slice (275–265 Ma). Panthalassic Ocean depths 2000 m+, Tethyan depths 200–500 m presumed depths. Solid line arrows, cold water; dashed line arrows, cool water.

the closest relationships are with the Verkhoyansk–Kolyma–Omolon regions of northeastern Siberia. Eastern Australian and New Zealand brachiopod genera, not found in western Australian faunas, such as *Terrakea*, *Anidanthus* and *Megousia* also demonstrate a bipolar distribution.

While a full review of brachiopod genera that exhibit bipolar distributions and the precise timing of their equatorial cross-overs is required, the close relationship of bipolar faunas can scarcely be attributed to parallel or convergent evolution. As for bivalve faunas (Astaf'yeva & Astaf'yeva-Urbaytis 1992) it is inferred that periodic migrations that crossed the palaeoequatorial region of Tethys occurred. Evidence suggests that during Kungurian times and again in the mid-Ufimian, trans-equatorial migrations took place, as for bivalves, but not by means of surface currents.

It is well known that modern deeper water oceanic currents can cross the Equator (Ingmanson & Wallace 1989). The deep water currents modelled by Kutzbach et al. (1990) run counter to the direction of the inferred surface currents also as in the modern Pacific. The schematic map in Fig. 9 shows an idealised deep water pattern for the Panthalassic Ocean and an intermediate depth pattern (200–500 m) for the Tethyan region (the latter currents presumed to be cooler than the surface waters). Such intermediate (in terms of depth and temperature) currents may have provided brief opportunities for larval stages of non-tropical genera to cross the Tethys, particularly during brief cooler episodes of climate change during the Permian. The time slice is for the Kungurian–Ufimian and currents are shown crossing the Equator from south to north. Directions of the cross-over currents are hypothetical and can possibly be tested by precise knowledge of the respective timing of the first appearances of genera in the Boreal and Austral (Notal) realms. Little tangible data exists for the existence of cooler, deeper water brachiopod faunas in the palaeo-equatorial regions of Tethys but elements of a cooler, deeper water fauna have been recorded from Sicily (Catalano et al. 1991) a region usually associated with tropical brachiopod faunas. It is noteworthy that the genera *Linoproductus* and *Costatumulus* (recorded as *Cancrinella*) were illustrated by these authors, the latter genus particularly recalling temperate Boreal and Austral assemblages.

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